Status of Laser/Lidar Working Group Requirements

by

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to

Working Group on Space-Based Lidar Winds
June 27-30, 2006
Welches, OR

Atmospheric Dynamics (Winds)

Science Requirements Subgroup

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(S) = Science lead
(T) = Technology lead

Authors also worked in Technology Challenge subgroups:
- Laser Transmitters
- Detection, Processing, Optics

NASA Laser/Lidar Technology Requirements Working Group

- First WG meeting: Nov. 8-9, 2005
- Second WG meeting: Dec. 14-15, 2005
- Community Forum: Jan. 10, 2006
- Third WG meeting: Jan. 11, 2006
- Fourth WG meeting: Feb. 7-8, 2006
- Writing of final report …
- June 9, 2006: draft copy of final report available at
  http://esto.nasa.gov/lwg/lwg.htm

Space Wind Measurement Requirements - 1

	Demo	Threshold	Objective	
Vertical depth of regard (DOR)	0-20	0-20	0-30	km
Vertical resolution:				
Tropopause to top of DOR	Not Req.	Not Req.	2	km
Top of BL to tropopause (~12 km)	2	1	0.5	km
Surface to top of BL (~2 km)	1	0.5	0.25	km
Number of collocated LOS wind measurements for horiz[A] wind calculation	2 = pair	2 = pair	2 = pair	-
Horizontal resolution[A]	350	350	100	km
Number of horizontal[A] wind tracks[B]	2	4	12	-
Velocity error[C] Above BL	3	3	2	m/s
Velocity error[C] In BL	2	2	1	m/s
Minimum wind measurement success rate	50	50	50	%
Temporal resolution (N/A for single S/C)	N/A	12	6	hours
Data product latency	N/A	2.75	2.75	hours

A – Horizontal winds are not actually calculated; rather two LOS winds with appropriate angle spacing and collocation are measured for an "effective" horizontal wind measurement. The two LOS winds are reported to the user.

B – The cross-track measurements do not have to occur at the same along-track coordinate; staggering is OK.

C – Error = 1σ LOS wind random error, projected to a horizontal plane; from all lidar, geometry, pointing, atmosphere, signal processing, and sampling effects. The true wind is defined as the linear average, over a 100 x 100 km box (or 175 km or 25 km) box centered on the LOS wind location, of the true 3-D wind projected onto the lidar beam direction provided with the data.

(original errata that have been corrected) (Added/clarified requirements during NASA ESTO ESTIPS Laser/Lidar Working Group)

Space Wind Measurement Requirements - 2

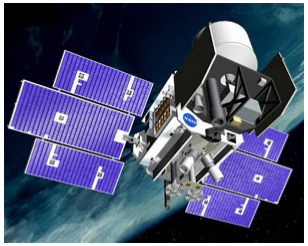
	Demo	Threshold	Objective	
Vertical location accuracy of LOS wind measurements	1	0.1	0.1	km
Horizontal location accuracy of LOS wind measurements	5	0.5	0.5	km
Allowed angular separation of LOS wind pair, projected to a horizontal plane	30-150	30-150	30-150	degree
Maximum allowed horizontal separation of LOS wind pair	50	35	35	km
Maximum horizontal extent of each horizontal^{A} wind meas.	175	100	25	km
Minimum horizontal cross-track width of regard of wind measurements	N/A	±400	±625	km
Maximum cross-track spacing of adjacent cross-track locations	N/A	350	100	km
Maximum design horizontal wind speed: Above BL Within BL	50 50	75 50	100 50	m/s m/s
Design 1σ wind turbulence level: Above BL Within BL	1 1	1.2 1	1.4 1	m/s
Max. LOS wind unknown bias error, proj. to a horiz. plane	1	0.1	0.05	m/s
Minimum design a priori velocity knowledge window, projected to a horizontal plane (using nearby wind measurements and contextual information)	26.6	26.6	26.6	m/s
Design cloud field: Layer from 9-10 km, extinction coefficient Layer from 2-3 km, 50% of lidar shots untouched, 50% blocked	 0.14 50, random	 0.14 50, random	 0.14 50, random	 km^{-1} %
Aerosol backscatter coeff.: 2 vertical profiles provided	Provided	Provided	Provided	m^{-1}sr^{-1}
Aerosol backscatter: Probability density function (PDF) PDF width	Lognormal Provided	Lognormal Provided	Lognormal Provided	m sr m^{-1}sr^{-1}
Atmospheric extinction coefficient: 2 vertical profiles provided	Provided	Provided	Provided	km^{-1}
Orbit latitude coverage	N/A	80N to 80S	80N to 80S	Degree
Downlinked data	All	All	TBD	-

(original errata that have been corrected) (Added/clarified requirements during NASA ESTO ESTIPS Laser/Lidar Working Group)

Atmospheric Winds

Recommended Roadmap

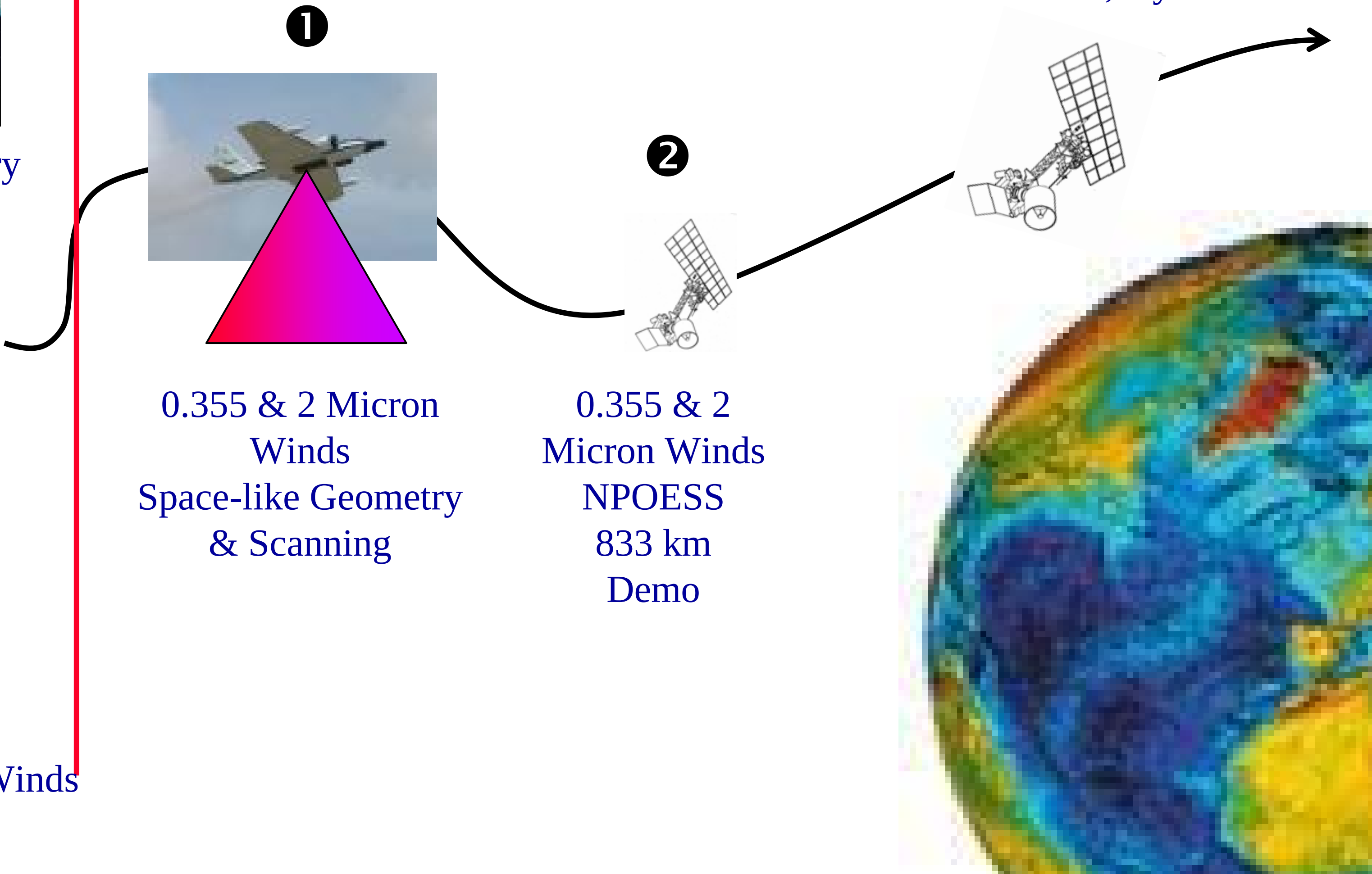
Past



1 Micron Altimetry

2 Micron Winds

0.355 & 2 Micron Winds



❶

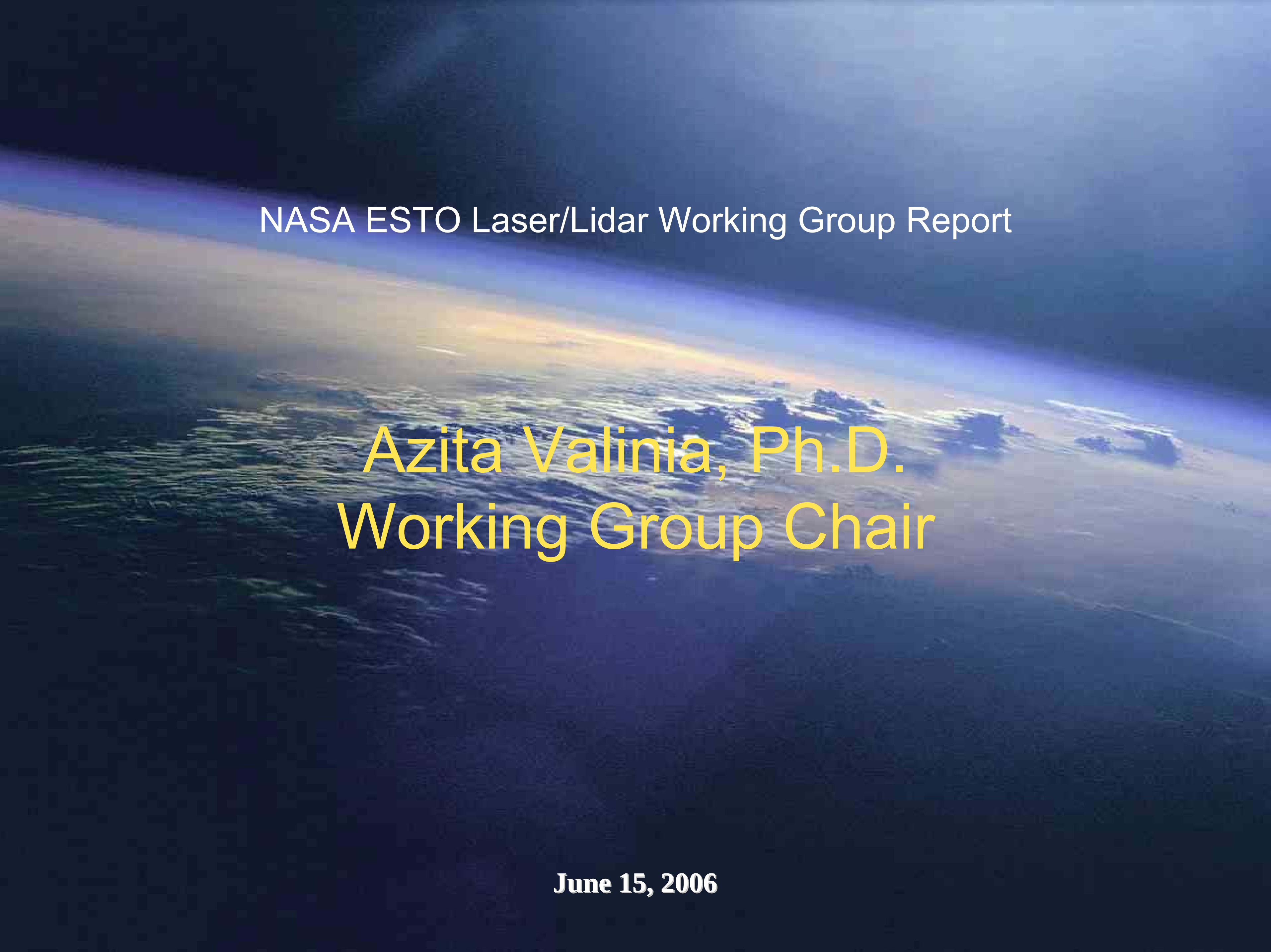
0.355 & 2 Micron
Winds
Space-like Geometry
& Scanning

❷

0.355 & 2
Micron Winds
NPOESS
833 km
Demo

❸

0.355 & 2
Micron Winds
NASA
400 km
Threshold, 3 yr.



NASA ESTO Laser/Lidar Working Group Report

Azita Valinia, Ph.D.
Working Group Chair

June 15, 2006

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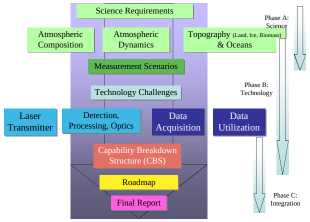
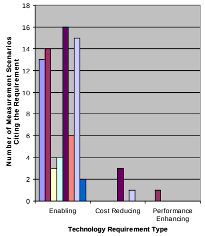
Outline



- Definition Process

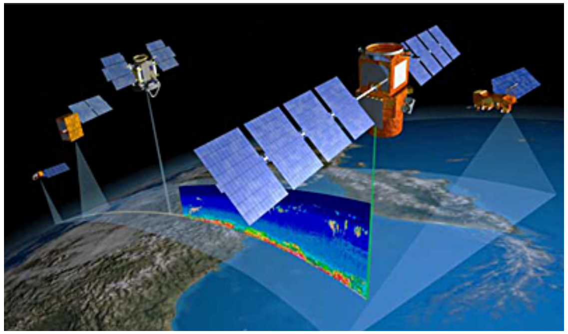


- Investment Priority Analysis

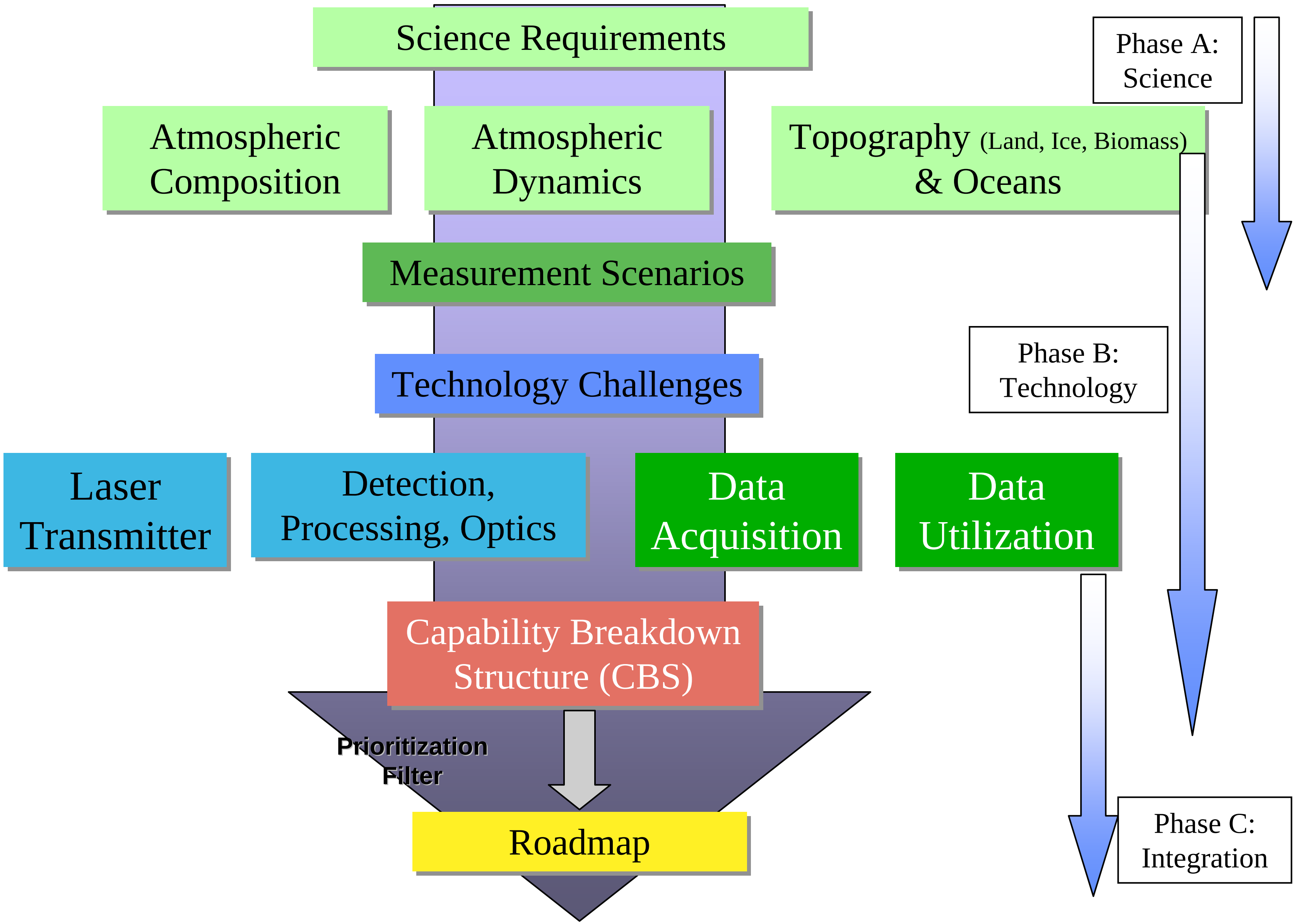
- Technology Roadmap

Working Group Charter

Develop a strategy for targeted technology development and risk mitigation efforts at NASA by leveraging technological advancement made by other government agencies, industry and academia, and move NASA into the next logical era of laser remote sensing by enabling critical Earth Science measurements from space.



Requirement Definition Process



Science Requirements

Atmospheric Composition

Atmospheric Dynamics

Topography (Land, Ice, Biomass) & Oceans

Measurement Scenarios

Technology Challenges

Laser Transmitter

Detection, Processing, Optics

Data Acquisition

Data Utilization

Capability Breakdown Structure (CBS)

Prioritization Filter

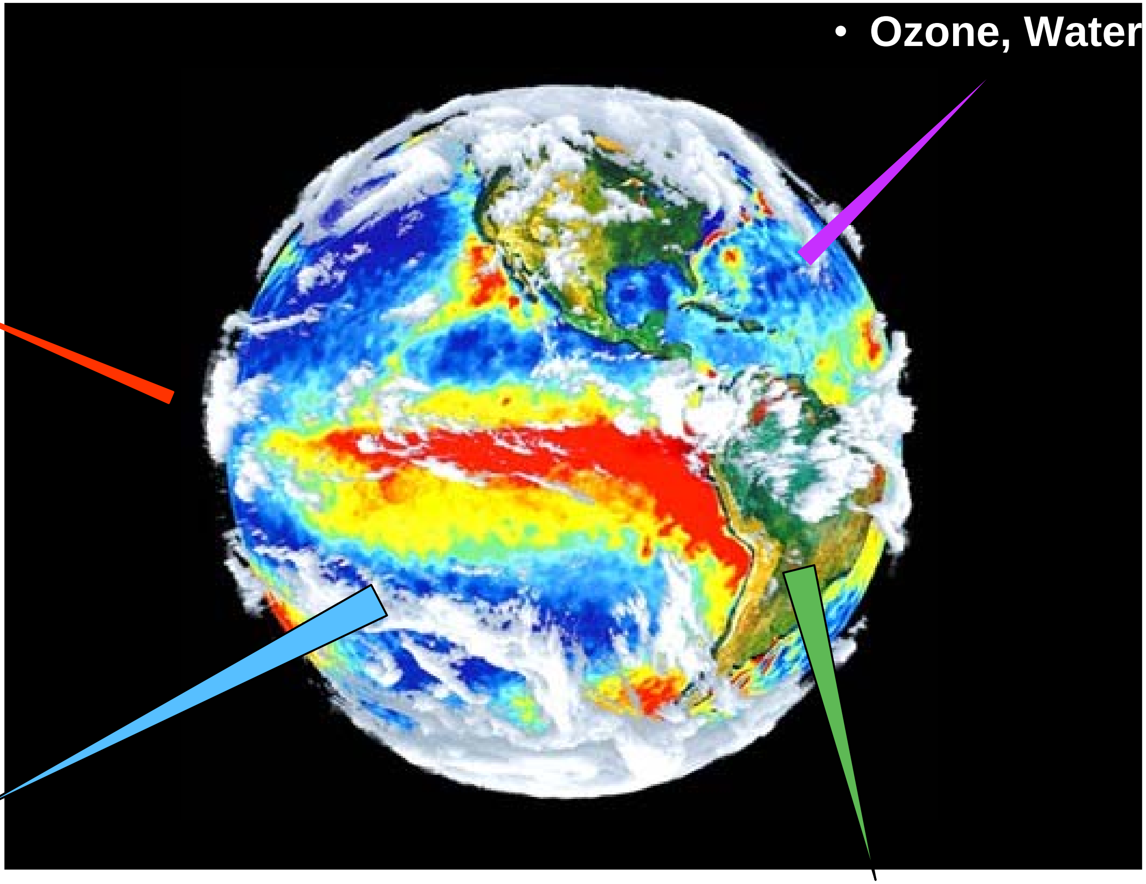
Roadmap

Phase A: Science

Phase B: Technology

Phase C: Integration

Laser Remote Sensing Techniques & Applications



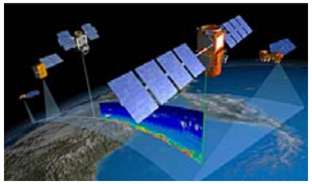
Differential Absorption Lidar (DIAL)
- Carbon Dioxide
- Ozone, Water Vapor

Doppler Lidar
- Wind Field

Backscatter Lidar
- Clouds
- Aerosols
- Phytoplankton Physiology
- Ocean Carbon/Particle Abundance

High-Precision Ranging & Altimetry
- Geodetic Imaging
- Vegetation Structure/Biomass
- Earth Gravity Field

Measurements ***Primarily*** Achieved by Laser Remote Sensing

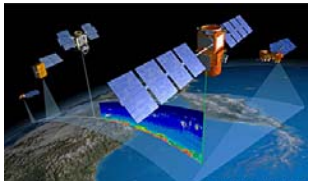


Weather

Tropospheric Winds - Doppler Lidar recognized as the *only* means for acquiring wind profiles with required precision (1 m/s, 100-km horizontal resolution).

Water Vapor Profile - DIAL recognized as the *only* technique for global moisture profile at high resolution (0.5 km vertical by 50 km horizontal) in the boundary layer, essential for understanding severe storm development

Measurements *Primarily* Achieved by Laser Remote Sensing



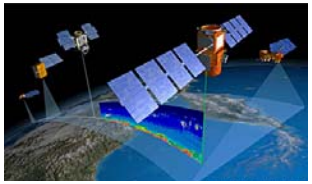
Atmospheric Composition

Tropospheric CO_2 Profile - DIAL is the only technique for high precision profiling of CO2 (0.3% mixing ratio, 2-km vertical scale), essential for understanding the global carbon cycle and global warming trends

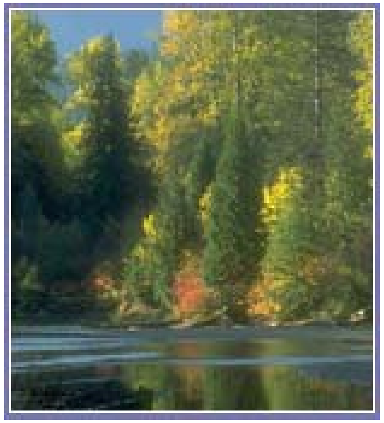
High Resolution Clouds & Aerosol - Backscatter lidar is the *only* technique for high vertical resolution (50m) measurements of optical properties of clouds and aerosols including planetary boundary height, cloud base, cloud top, cloud depolarization, and aerosol scattering profiles needed in climate modeling

High Resolution Tropospheric Ozone Profile - DIAL is the *only* technique for global tropospheric ozone profiling with high resolution (1-2 km vertical, 100 km horizontal), essential for understanding atmospheric processes in the troposphere

Measurements ***Primarily*** Achieved by Laser Remote Sensing



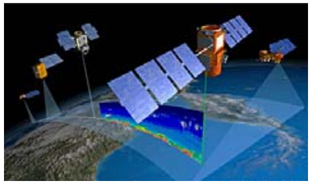
Carbon Cycle & Ecosystems



3D Biomass- Lidar Altimetry is the only technique for profiling 3D vegetation canopies to the required vertical accuracy of 0.5 m and horizontal resolution of 5-20m

Phtoplankton Physiology & Ocean Carbon Abundance - Lidar is the *only* method for measuring particle profiles in the oceans' mixed layer of 5m resolution depth or better, necessary to understand how oceanic carbon storage and fluxes contribute to the global carbon cycle

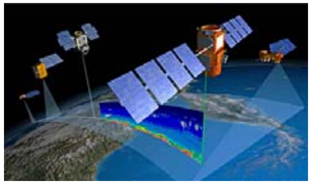
Measurements ***Primarily*** Achieved by Laser Remote Sensing



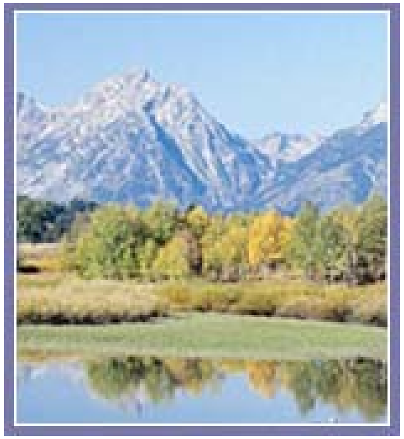
Climate Variability and Change

High Resolution Ice Surface Topography - Lidar Altimetry is the only technique for profiling ice surface topography and changes of less than 1 cm/year, essential for understanding climate change

Measurements *Primarily* Achieved by Laser Remote Sensing



Earth Surface and Interior

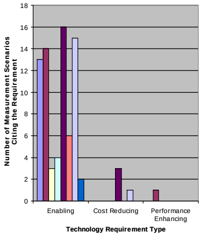


Earth Gravity Field 3D - Improved range measurements provided by laser interferometry will improve Earth gravity field observation to less than 100 km and 10-day resolution with an accuracy of less than 1cm equivalent surface water height

Terrestrial Reference Frame - Improved satellite laser ranging network will provide a factor of 5-10 improvement in reference frame and satellite precision orbit determination over current measurements

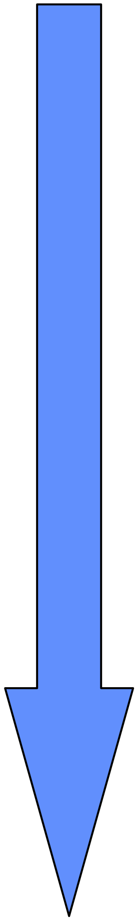
Outline

- Definition Process



- Investment Priority Analysis
  - Prioritization Criteria
  - Analysis
- Technology Roadmap

Technology Prioritization Criteria



1. Scientific Impact
2. Societal Benefit
3. Measurement Scenario Uniqueness
4. Technology Development Criticality
5. Technology Utility
6. Measurement Timeline
7. Risk Reduction

Scientific Impact

The degree to which the proposed measurement *via lidar technique will impact* our understanding of the Earth System and will help answer the overarching questions defined in NASA Earth Science Research strategy.

Impact Timeline

Tropospheric Winds --> Severe Weather Prediction

Tropospheric CO_2 Profile --> Global Warming Trends and Air Quality

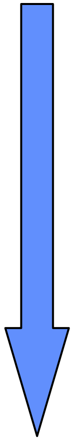
High Resolution Polar Ice Topography Change --> Climate Change Prediction

3D Biomass --> Carbon Cycle, Sources/Sink, Climate Change Prediction

Phytoplankton Physiology --> Oceanic Carbon Cyle

Societal Benefit

The degree to which the proposed measurement has the *potential to improve life on Earth*.

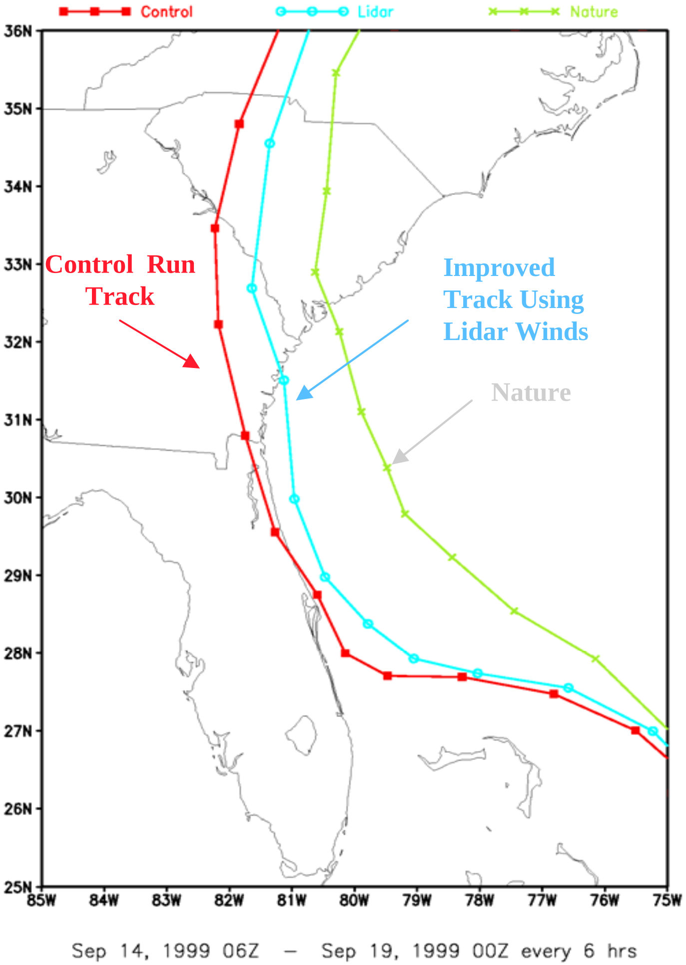


Near- Term Benefits

1. Severe Weather Prediction (Trop Wind)
2. Air Quality/Assessment of Global Warming (CO_2)
3. Long Term Climate Change (Ice mass, Biomass, CO_2)

Long-Term Benefits

Prediction of Hurricane Tracks Using Trop Wind Data



Credit: Ardizzone &Terry 2006

Measurement Scenario Uniqueness

Whether Lidar technique is the *primary or unique technique* for making the proposed measurement.

- **Tropospheric Winds**
- **CO_2 Vertical Profile**
- **Vegetation Biomass**
- **High Resolution Ice Surface Topography**
- **Phytoplankton Physiology & Functional Groups**
- High Spectral Resolution Aerosol
- Ocean Carbon/Particle Abundance
- Earth Gravity Field
- Terrestrial Reference Frame

Also appeared under previous criteria

Technology Development Criticality

Whether the development of the proposed technology *enables new and critical measurement capabilities* as opposed to provide incremental improvement in the measurement.

Technology Criticality Priority

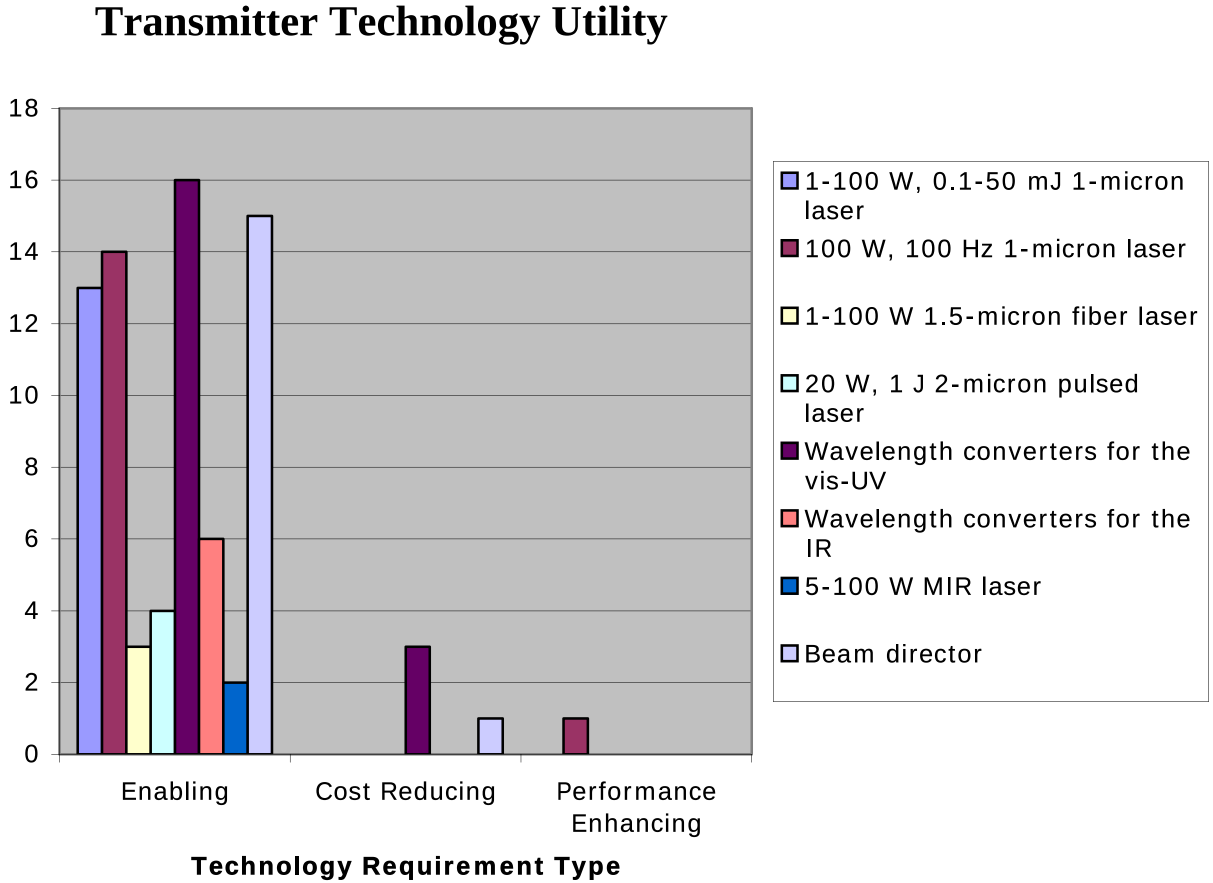
Enabling

Cost Reducing

Performance Enhancing

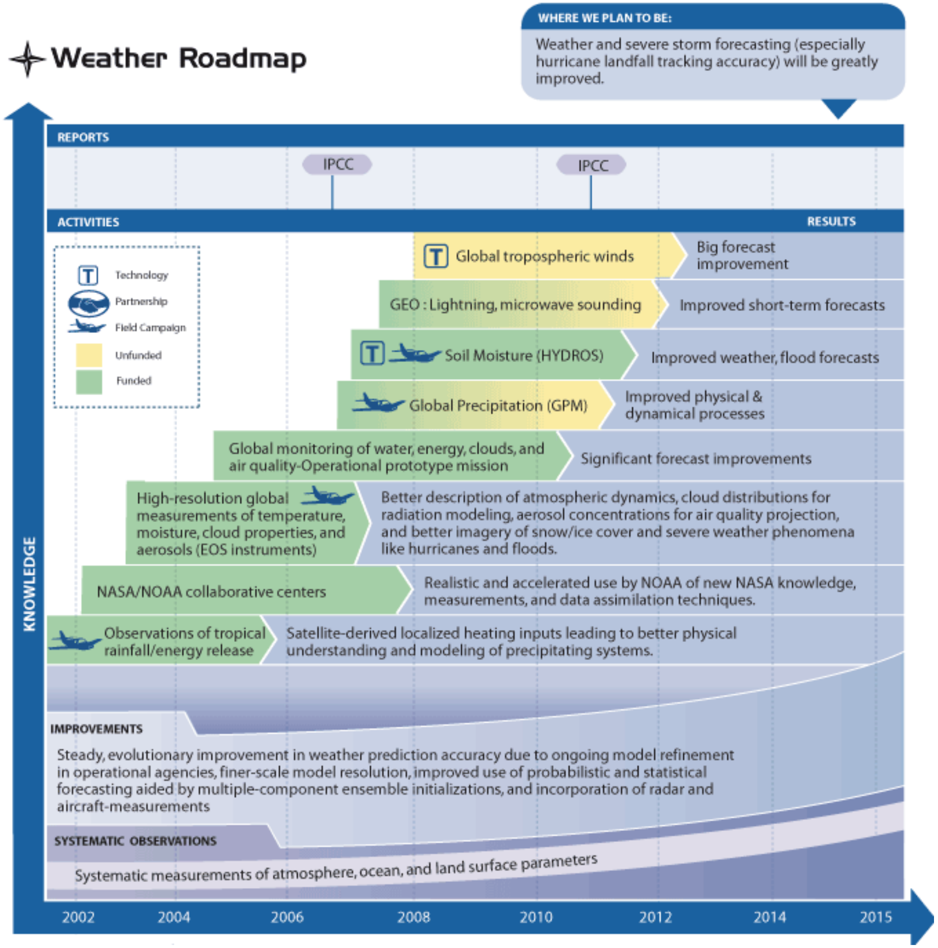
Technology Utility

The degree to which the technology makes significant *contribution to more than one measurement application,* i.e. is cross cutting in utility.



Measurement Timeline

Determined by the time horizon *<u>when a particular measurement is needed</u>*, as articulated in NASA's Earth Science Research Strategy.



Weather Roadmap

WHERE WE PLAN TO BE:

Weather and severe storm forecasting (especially hurricane landfall tracking accuracy) will be greatly improved.

Activities	Results
Global tropospheric winds	Big forecast improvement
GEO : Lightning, microwave sounding	Improved short-term forecasts
Soil Moisture (HYDROS)	Improved weather, flood forecasts
Global Precipitation (GPM)	Improved physical & dynamical processes
Global monitoring of water, energy, clouds, and air quality-Operational prototype mission	Significant forecast improvements
High-resolution global measurements of temperature, moisture, cloud properties, and aerosols (EOS instruments)	Better description of atmospheric dynamics, cloud distributions for radiation modeling, aerosol concentrations for air quality projection, and better imagery of snow/ice cover and severe weather phenomena like hurricanes and floods.
NASA/NOAA collaborative centers	Realistic and accelerated use by NOAA of new NASA knowledge, measurements, and data assimilation techniques.
Observations of tropical rainfall/energy release	Satellite-derived localized heating inputs leading to better physical understanding and modeling of precipitating systems.

IMPROVEMENTS

Steady, evolutionary improvement in weather prediction accuracy due to ongoing model refinement in operational agencies, finer-scale model resolution, improved use of probabilistic and statistical forecasting aided by multiple-component ensemble initializations, and incorporation of radar and aircraft-measurements

SYSTEMATIC OBSERVATIONS

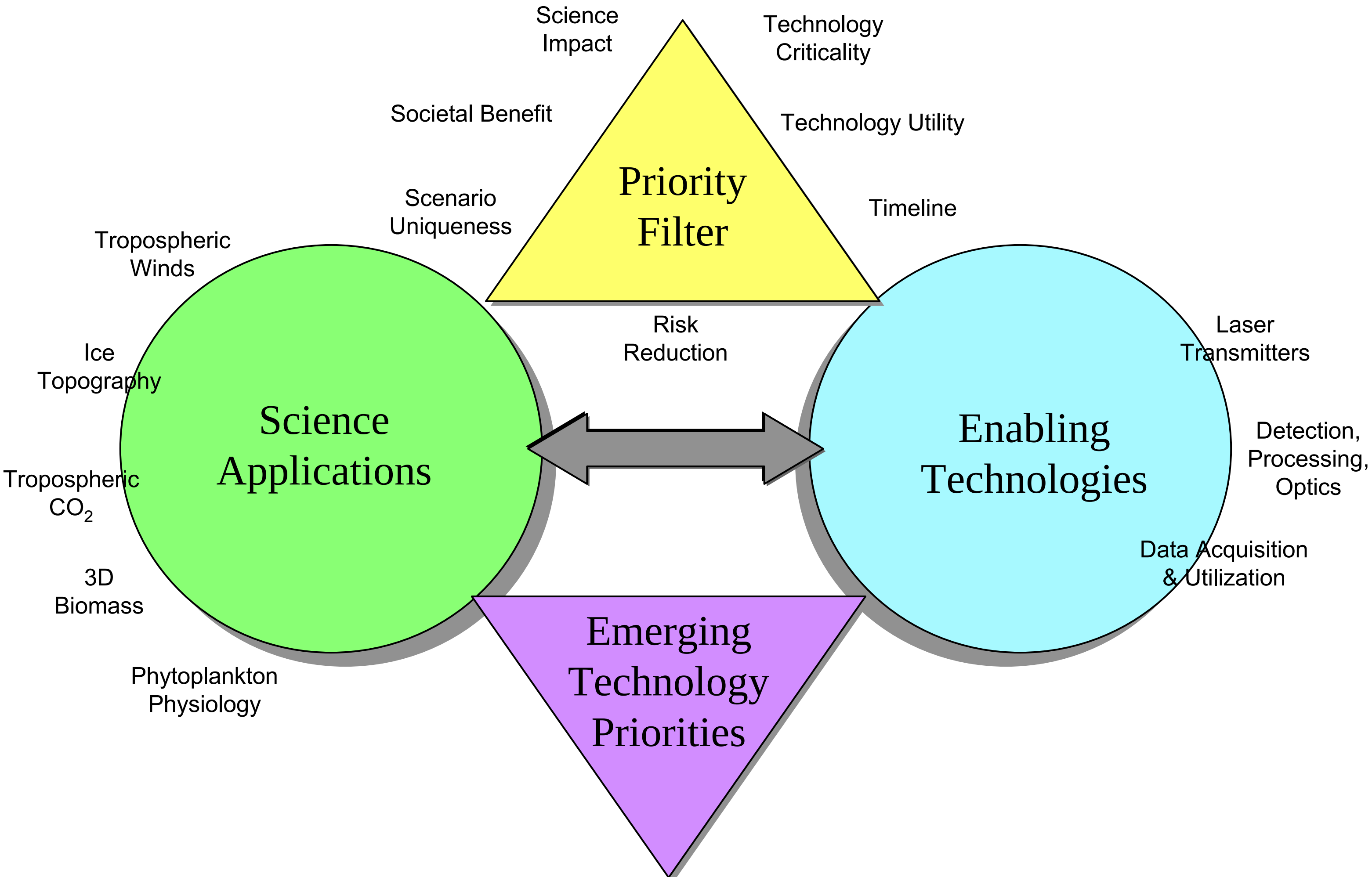
Systematic measurements of atmosphere, ocean, and land surface parameters

Risk Reduction

The degree to which the new technology *mitigates the risk of mission failure.*

- Laser Transmitters present the greatest development challenge and pose the greatest risk.
- Risk reduction laser transmitter technologies are of highest priority.

Filtering Requirements Leads to Technology Priorities



Science
Impact

Technology
Criticality

Societal Benefit

Technology Utility

Priority
Filter

Scenario
Uniqueness

Timeline

Tropospheric
Winds

Risk
Reduction

Laser
Transmitters

Ice
Topography

Science
Applications

Enabling
Technologies

Detection,
Processing,
Optics

Tropospheric
CO_2

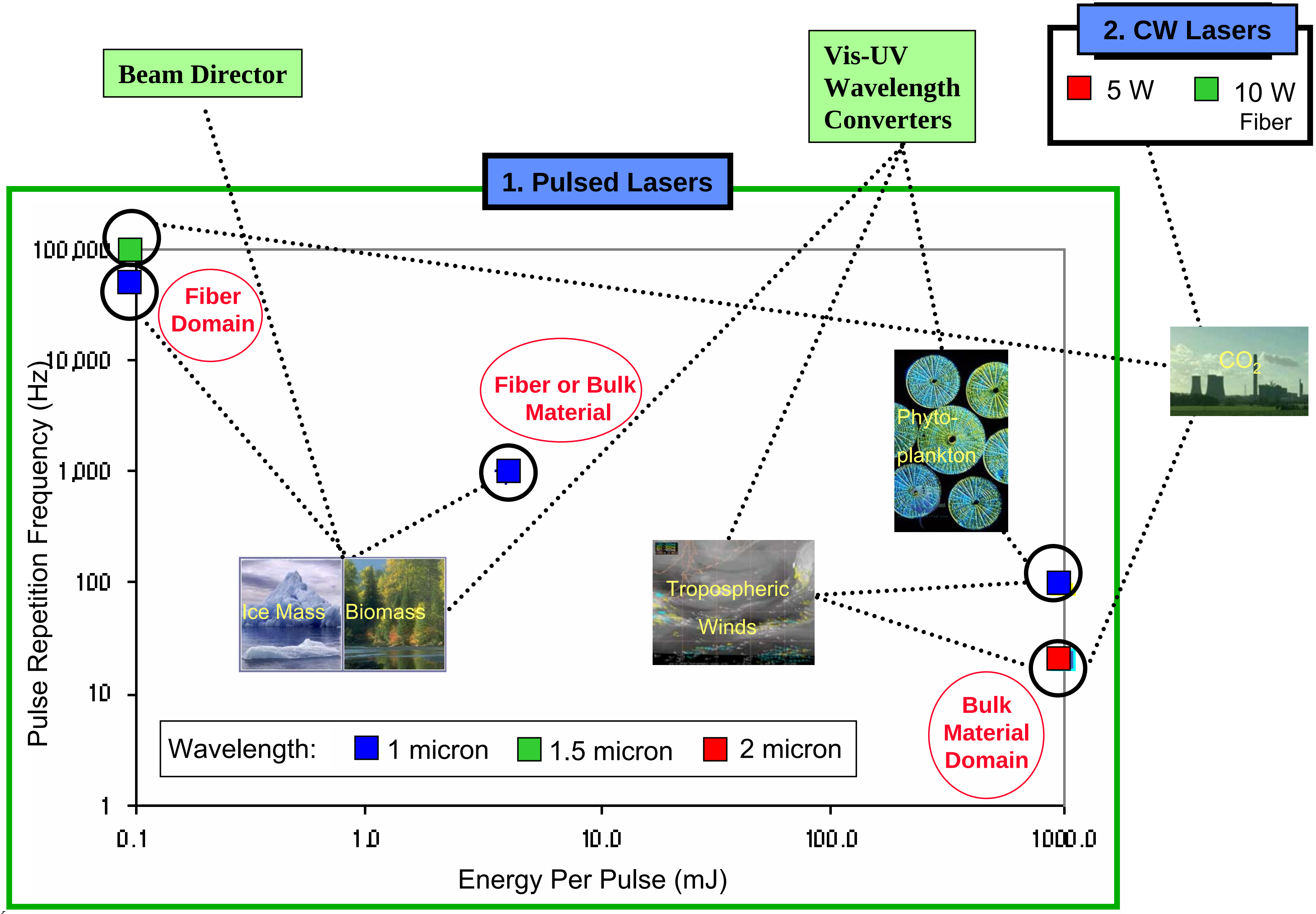
Data Acquisition
& Utilization

3D
Biomass

Emerging
Technology
Priorities

Phytoplankton
Physiology

Required Laser Transmitter Capabilities



Beam Director

Vis-UV Wavelength Converters

2. CW Lasers

🟥 5 W 🟩 10 W Fiber

1. Pulsed Lasers

Fiber Domain

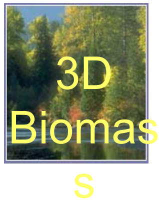
Fiber or Bulk Material

Bulk Material Domain

Wavelength: 🟦 1 micron 🟩 1.5 micron 🟥 2 micron

Laser Transmitter Priorities

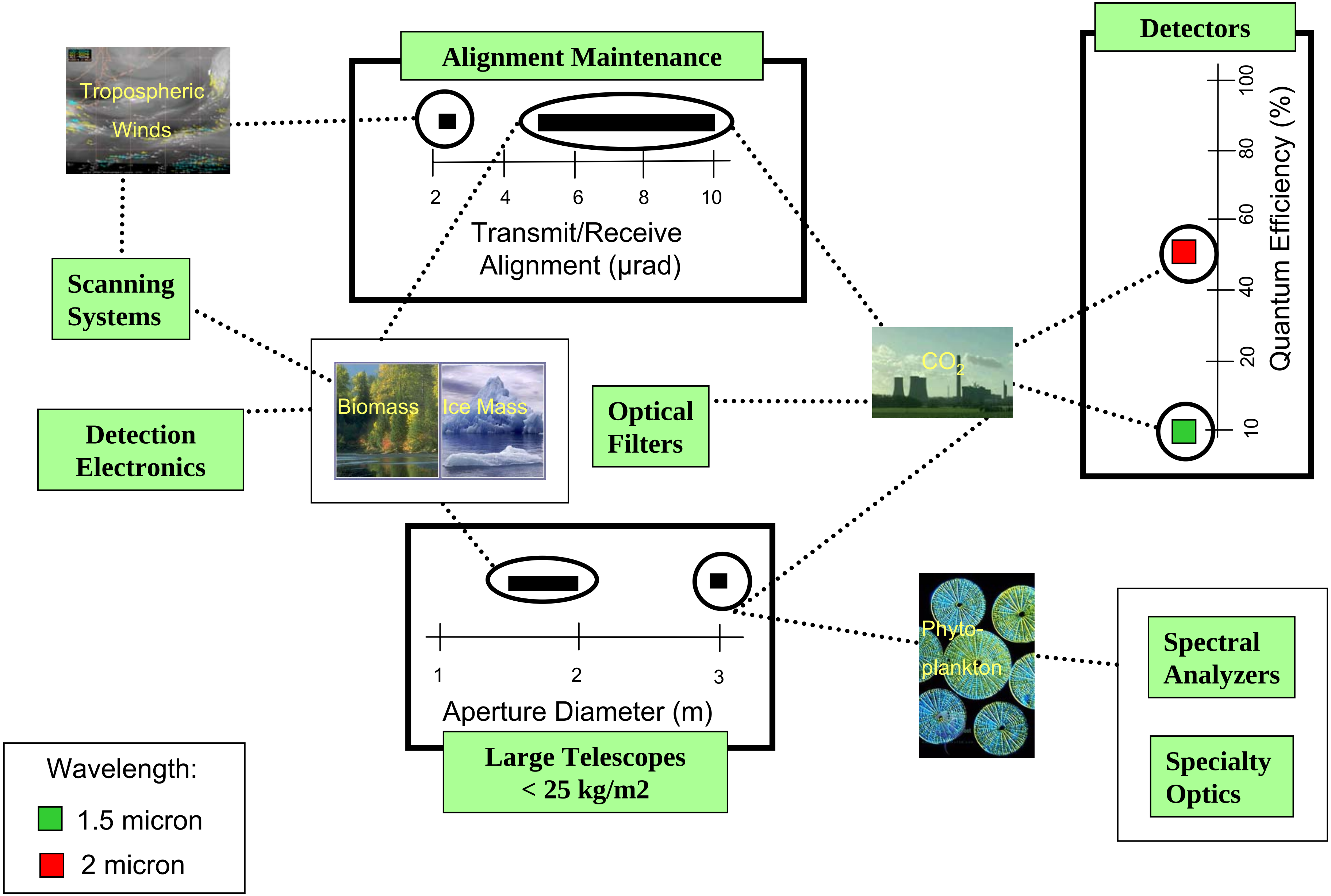
2



1-100 W, 0.1-50 mJ, 1 micron Fiber or Bulk Laser		0.1 mJ/75kHz @1064nm, 5ns pulse, WPE 10% **4**		0.1 mJ/75kHz @1064nm, 5ns pulse, WPE 10% **4**	
100 W, 100Hz, 1 micron Laser	1 J/100 Hz, single freq @ 1064nm, WPE 6-8% **5**	100 mJ/100 Hz @ 1064 nm, pulselength ~3 ns **7**			1 J/20-100 Hz, single freq WPE 6-8% **3**
1-100 W, 1.5 micron Fiber Laser			10 W cw OR 0.1 mJ/100 kHz **4**		
5-20 W, 2 micron Laser	0.5 J/10 Hz, single freq, WPE > 1.4% **4**		1 J/20 Hz double pulsed, WPE 3-5% AND/OR 5 W CW **3**		
Wavelength Converters	340mJ/100Hz @355nm,>40% harmonic conv. from 1064nm **4**	20/100&500mJ/20-100 Hz @532nm conv eff. >50% **5,3**	10 W CW @ 1.6 micron 1064-nm pumped OPO **4**		500 mJ/20-100 Hz @ 532 nm **3**
Beam Director				1000 beam positions across 1-2° FOV **2**	

* Current TRL designated in lower right corner.

Required Lidar Receiver Capabilities



Alignment Maintenance

Detectors

Scanning Systems

Detection Electronics

Optical Filters

Large Telescopes < 25 kg/m2

Spectral Analyzers

Specialty Optics

Wavelength:

🟩 1.5 micron

🟥 2 micron

Lidar Receiver Priorities

	Trop Wind DEMO	Ice Mass	CO_2	3D Biomass	Phyto-plankton
Alignment Maintenance	C4 5 μrad (coherent), 50 μrad (direct) D7		5-10 μrad transmit/receive boresight 7		
Scanning Systems	C5 Conical or step-stare, full azimuth at 30-50°, nadir D3			Addressable FOV between 1-2° 2	
Large Telescopes			3m, < 25 kg/m² 2	1.5-2m dia, 4-20 μrad blur circle 2	3m, < 25 kg/m² 2
Detectors and Electronics			1.5 & 2 micron detectors with high quantum efficiency 4	8 bit, 500 Msample/sec streaming digitizer w/integrated pulse finding 5	
Opt. Filters/Specialty Optics			200 pm, 60% transmission 4		1-3nm notch filter/90%trans 4

* Current TRL designated in lower right corner.

Data Acquisition and Utilization Priorities

2

	Trop Wind DEMO	Ice Mass	CO_2	3D Biomass	Phytoplankton
Air/Ground Validation Sys.	Cal//Val ≤1 hr* 2	Cal/val < Days 4		Cal/Val: <1% Error 4	
Adaptive targeting	OSSE ≥ 3 instruments 3		Plan & Execution: <3 hr 4		
Intelligent Sensor H&S			Laser life diagnosis < days 4	Laser life prognosis < days 2	
On-board Sensor Control		RT Event detection (clouds) 4	Control sys. error = 4μrad 3		

*Required for operational weather and air pollution measurement systems

* Current TRL designated in lower right corner.

Outline

- Definition Process
- Investment Priority Analysis
- Technology Roadmap

NASA ESTO Laser/Lidar Technology Roadmap

LWG 2006

Near-Term | Mid-Term | Far-Term

	Trop Wind DEMO (possibly with HSRL)	Ice Mass	CO_2	3D Biomass	Phytoplankton Physiology
TRANSMITTER					
1-100 W, 0.1-50 mJ, 1 micron Fiber or Bulk Laser		0.1 mJ/75kHz @1064nm, 5ns pulse, WPE 10% 4		0.1 mJ/75kHz @1064nm, 5ns pulse, WPE 10% 4	
100 W, 100Hz, 1 micron Laser	1 J/100 Hz, single freq @ 1064nm, WPE 6-8% 5	100 mJ/100 Hz @ 1064 nm, pulselength ~3 ns 7			1 J/20-100 Hz, single freq WPE 6-8% 3
1-100 W, 1.5 micron Fiber Laser			10 W cw OR 0.1 mJ/100 kHz 4		
5-20 W, 2 micron Laser	0.5 J/10 Hz, single freq, WPE > 1.4% 4		1 J/20 Hz double pulsed, WPE 3-5% AND/OR 5 W CW 3		
Wavelength Converters	340mJ/100Hz @355nm,>40% harmonic conv. from 1064nm 4	20/100&500mJ/20-100 Hz @532nm conv eff. >50% 5,3	10 W CW @ 1.6 micron 1064-nm pumped OPO 4		500 mJ/20-100 Hz @ 532 nm 3
Beam Director				1000 beam positions across 1-2º FOV 2	
RECEIVER					
Alignment Maintenance	5 µrad (coherent), 50 µrad (direct) C4 D7		5-10 µrad transmit/receive boresight 7		
Scanning Systems	Conical or step-stare, full azimuth at 30-50º, nadir C5 D3			Addressable FOV between 1-2º 2	
Large Telescopes			3m, < 25 kg/m² 2	1.5-2m dia, 4-20 µrad blur circle 2	3m, < 25 kg/m² 2
Detectors and Electronics			1.5 & 2 micron detectors with high quantum efficiency 4	8 bit, 500 Msample/sec streaming digitizer w/integrated pulse finding 5	
Opt. Filters/Specialty Optics			200 pm, 60% transmission 4		1-3nm notch filter/90%trans 4
DATA					
Air/Ground Validation Sys.	Cal//Val ≤1 hr* 2	Cal/val < Days 4		Cal/Val: <1% Error 4	
Adaptive targeting	OSSE ≥ 3 instruments 3		Plan & Execution: <3 hr 4		
Intelligent Sensor H&S			Laser life diagnosis < days 4	Laser life prognosis < days 2	
On-board Sensor Control		RT Event detection (clouds) 4	Control sys. error = 4µrad 3		

NOTE: Current TRL in lower right corner.

Winds: C=coherent, D=direct

* Required for operational weather and air pollution

Operation

Kavaya – Lidar WG

Overall Recommendation

- Highest priority measurement(s) must be identified at the Agency level first.
- Technology Requirements for each measurement in the area of transmitters, DPO, and DADU are tightly coupled.
- Technology development to satisfy the priority measurement(s) must then targeted and coordinated in the three categories in order to get maximum return on investment.

Kavaya/Gentry Conclusions

- Fast-paced experience
- Impossible to AND {include everyone who has something to contribute, afford the effort, come to an agreement, finish}; therefore accept the imperfections of it all
- Draft report strongly endorses technology development for tropospheric wind mission
- Tall poles not explicitly captured: coherent winds = laser lifetime, alignment; direct winds = scanner, photon efficiency
- Still time to (quickly) give corrections to draft report
- Future NASA opportunities for funding might reflect the priorities of this report
- Many thanks to Ramesh Kakar for participating & advocating
- Many thanks to Winds WG members who contributed